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An overview of Artificial Intelligence coupled with IoT solutions to improve food security

Ashok Kumar[1] and Mohan Kumar Sinha*[2]

[1]*Department of Agricultural Engineering, Bihar Agricultural College, Bihar Agricultural University, Sabour-813210, Bhagalpur, Bihar, India*
[2]*Department of Agricultural Engineering, Irrigation Research Sub Station, Araria, Bihar Agricultural University, Sabour-813210, Bhagalpur, Bihar, India*

ABSTRACT

The food sector proposes significant capital savings and resource optimization through the application of artificial intelligence (AI) to improve food quality and security. In addition, comprehension of machine learning (ML) methods is necessary for their efficacy. Examining how industrial automation is essential to the effective application of this new technology is where the gap resides. In order to close this gap, this review investigates how AI might improve food safety by establishing more transparent supply chain management system. Thus, investigating possible AI applications for identifying the quality of food and agricultural products, such as artificial neural networks (ANN) and convolutional neural networks (CNN), is the main goal. Reducing human intervention and effort is the main objective of using these AI applications. In terms of theoretical understanding and model interpretation, these approaches have benefits and drawbacks.

Keywords: *machine learning, artificial intelligence, neural networks,food quality, food sensors, optimized production, robotics.*

1. Introduction

It is estimated to increase global food production to 60–110% for feeding 9–10 billion people by 2050 [1]. The sustainability of the agricultural industry is essential to ensuring food security and reducing hunger for the growing population of world. Food, often known as rations, is universally acknowledged as a basic human need and the end result of farming; it is produced by farmers and distributed by them. The agricultural landscape has been significantly impacted by the interaction between agriculture and key factors such as population dynamics, climate change, sustainability, and the size of the global market. The products produced by food companies are essential for the continual development of any nation [2]. Crop management systems and other cutting-edge agricultural technology are essential for boosting productivity. Due to the growing risks associated with climate change, farmers must implement strict measures to mitigate its impacts in order to preserve agricultural production [3].The growth of the national economy and the global economy are also significantly influenced by it. Thus, it is crucial to ensure the safety of food sector goods and their quality through appropriate distribution. In addition, an extensively documented traceability system is now essential to the quality management of food chain. It also has major impact on the expansion of both the domestic and international economies. Therefore, proper distribution is essential to ensuring the quality and safety of food industry products. Furthermore, the quality management of the food chain today depends on traceability system that has been well documented. Recent technological advancements have opened the door for innovative solutions across a range of sectors, including agriculture. The concept of smart farming emerged as a result of the incorporation of cutting-edge technologies like automation, robots, blockchain, embedded electronics, and the Internet of Things, which have transformed modern farming methods. The clever use of data-driven technology to raise sustainability of agricultural practices productivity, and efficiency is part of this new paradigm.

To have a significant competitive edge, smart agriculture will need to include new technologies like the IoT. In order to satisfy the demands of the expanding population, agricultural production needs to increase [4]. AI-based or autonomous systems are frequently utilized in every technological domain. It makes the system feasible to efficiently optimize problems, computerize the food industry, and modify its goods globally. By employing a computerized system, the industry can evaluate and guarantee the best situation conditions such as seed selection, crop monitoring, watering, and temperature monitoring may be improved, leading to better food sector products [5]. IoT is enhancing farming practices by offering intelligence and connection through intelligent livestock monitoring and automated irrigation systems. Such that intelligent agriculture based on the blockchain and IoT may provide the agricultural industry with significant benefits including increased crop quality, decreased cost and waste, and improved operational efficiency [6]. AI could help in food preparation, transportation, and storage. Robotics and intelligent drones are two examples of intelligent technology that can play a significant role in lowering packaging costs. It will also help with food transportation, completing work in dangerous conditions, and manufacturing high-quality products. The role of AI in the food industry is presented in Figure 1.

*Corresponding Author: ***Satish Kumar and Mohan Kumar Sinha***

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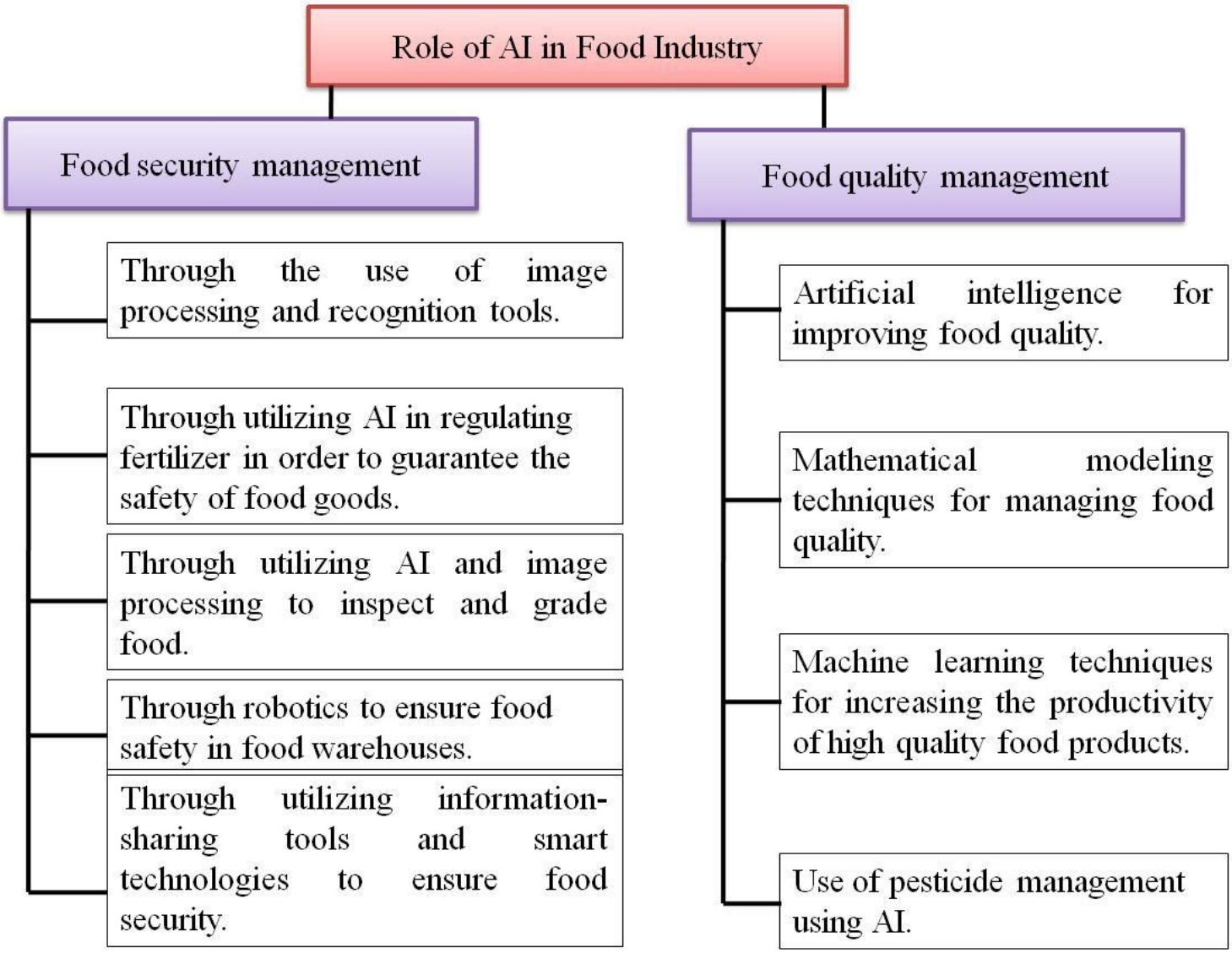

Figure 1: Application of AI in food industry [7]

One essential element of artificial intelligence is ML, which enables individuals to be more creative and efficient. Three main functions comprise machine learning: reinforcement learning, unsupervised learning, and supervised learning. In this method of supervised learning, variables are assigned to the intended output variable. Algorithms are used in supervised learning methods. Deep learning, genetic algorithms, ANNs, and clustering are examples of unsupervised learning. The extensive application of machine learning models to handle complex and diverse data in order to address food security issues shows how AI may significantly improve food security. One potential solution to food security problems is the development of early warning systems for food security using machine learning algorithms [8]. The food industry has benefited from a number of possible solutions offered by AI and ML, including the ability to optimize production and conserve resources through precision decision-making and accurate predictions. In order to overcome understanding obstacles and enhance food quality and global food security, AI technologies employ algorithms to assess performance, spot trends, and forecast unanticipated issues or occurrences. AI-enabled sensors can accurately identify plant diseases and evaluate soil quality, enabling prompt actions. Better planning and distribution are made possible by sophisticated algorithms that predict agricultural yield. AI also increases food safety by closely following safety guidelines and continuously checking for contamination levels. When combined, these technologies lower food waste and guarantee a steady supply of food worldwide [9]. In recent decades, the food sector has embraced artificial AI in response to the growing global population and the resulting rise in food consumption. The capacity of these intelligent systems to handle tasks like food quality evaluation, control tools, food categorization, and prediction has led to an increase in demand from the food sector. In order to help identify the most effective methods for promoting future advancements in AI and the food industry, this article discuss about their important and applications[10].

2. AI in Food quality management

The prediction of food quality in precision agriculture and food technology has been revolutionized with the introduction of AI. Time-consuming inspection and sample destruction are the main challenges to keeping track of food item quality and expiration dates. Rapid, accurate, and effective analysis is required to determine the quality of food. Data analysis is essential for assessing the quality of food since many datasets contain duplicate and unnecessary information has emerged as a potent analytical tool for evaluating the quality of different food and agricultural products as a result of the digital revolution. Two essential elements of artificial intelligence are machine learning and deep learning. In addition to addressing

post-harvest loss, machine learning and deep learning enhanced food quality shelf life prediction, authenticity, and quality management. ANN, is a kind of machine learning which is frequently used to assess the quality of food products [11].

ANNs are the most widely utilized AI technology for evaluating the quality of food. A mathematical model built on nodes of linear or nonlinear processing characteristics is called an ANN. ANN has demonstrated the potential advantages of evaluating the quality of agricultural products and foods including olive oil, potatoes, coconuts, and durians [12]. The dry matter content of mangos was predicted using an ANN model, and excellent results were achieved across the board [13]. The relationship between fried temperature of fish cooking time, oil content, and nutritional value was established by Sadhu et al. [14]. His research revealed that by carefully adjusting the frying parameters with the ANN model, the nutritional makeup of fried fish was restored. The rising demand for quality food items affects health of consumer and due to lack of awareness. Therefore, the advancement of AI makes it possible for tools to be readily accessible for monitoring the quality evaluation of different foods and agricultural produces. In order to anticipate demand, supply chain dynamics, and consumer preferences in food prediction, sophisticated algorithms will improve production and distribution operations. The explanation is on increasing food industry productivity and decreasing waste, which is important because it has the potential to transform resource allocation and promote more sustainable food chain. Artificial intelligence in food technology, particularly in packaging systems, will create opportunities as well as obstacles in the future [15]. The capacity of AI to guarantee data quality, preserve provenance information for transparency and arrange metadata from many sources is essential to its responsible and explicable use in food quality management [16]. AI has the ability to enhance food processing and agricultural methods, as seen by its positive effects on agricultural output, especially in crop production [17].

2. Food processing with AI analytics

AI must be used by the food sector to enhance customer satisfaction, optimize supply chain management, decrease batch size, and discover innovative, affordable methods of reaching and serving consumers. One of the primary objectives of this business is to provide reliable, standard techniques for product quality control. The emergence of new technologies that leverage AI to enhance productivity, quality, and efficiency has brought about significant changes in the food processing industry. AI may enhance several aspects of the food industry, such as supply chain management, quality assurance, food manufacturing, and processing, through the use of big data analytics, machine learning and artificial neural networks. The food supply chain may include artificial intelligence to improve decision-making and operational effectiveness. AI in food processing holds potential raising agricultural output, enhance quality control, and reduce environmental impact.

AI, for instance, can improve food safety and quality by simplifying the evaluation of food and agricultural goods [18]. Precision farming using AI has reduced agricultural emissions by 20%, contributing to environmental sustainability [19]. Food production, safety, and supply chain management have all been profoundly transformed by the widespread application of AI analytics in food processing as presented in Table 1. AI technology has increased safety, traceability, and resource efficiency while improving food yield, quality and nutrition [20]. Food chemistry and molecular analysis studies are two examples of AI applications in the food industry where AI techniques gain knowledge about the characteristics and composition of food [21]. Food supply chains have become more efficient, precise, and traceable because of AI's assistance in digitizing and automating them through the use of technologies like blockchain, the Internet of Things, and Radio Frequency Identification (RFID).

Table 1: Applications of AI in food processing

Application	Description	Reference
Food Yield, Quality, and Nutrition Enhancement	Food processing is being revolutionized by AI, which maximizes food output, guarantees excellent quality, and improves nutritious value.	[22]
Food Chemistry and Molecular Analysis Research	Research on food chemistry and molecular analysis is advanced by AI techniques that offer insights into the content and characteristics of food.	[21]
Analytical Prediction for Operational Effectiveness	In the food and beverage sector, artificial intelligence (AI) and big data analytics enhance operational effectiveness and quality using sophisticated predictive modeling approaches.	[23]
Automating and Digitizing Food Supply Chains	AI enables automation and digitization, combining blockchain, RFID, and IoT to improve the accuracy, traceability, and efficiency of the food supply chain.	[24]
Optimization of Intelligent Production Control Systems	Combining cloud computing, IoT, AI, and machine learning with intelligent production control systems optimizes food manufacturing procedures.	[25]
Inspection of Food Quality Using Big Data Technologies	AI-driven quality inspection is creating new opportunities in the agri-food sector by utilizing big data technology and high-performance computing.	[26]
Addressing Vulnerable Populations' Food Insecurity	AI examines eating and exercise habits, helping to develop focused interventions to enhance nutrition and food security for disadvantaged groups like Alaska Natives and American Indians.	[27]

4. Identifying food textures with AI

One of the primary factors affecting food acceptance is texture and quality.

Food texture and quality prediction models have been created using ANN modelling. Because ANN can evaluate complex data with many factors, learn from examples, and incorporate additional variables as needed, it is affordable and suitable for non-linear problems [28]. This could be a way to standardize yogurt texture, which would enable the identification of factors affecting the product's anticipated quality of product. The effectiveness of deep learning and analysing food textures, particularly when evaluating RGB and spectrum photos of food goods, has been highlighted by recent studies [28].

However, there are still challenges in developing multi-class food item recognition models, particularly when it comes to handing the colour and texture similarity of food items [29]. Furthermore, deep learning techniques like deep neural networks (DNNs) have demonstrated potential in determining the concentrations of commercially manufactured puréed foods. This suggests the ability to adapt and change these methods for different uses.

5. AI to optimize the food supply chain

Food supply chains are now more efficient and productive thanks to the integration of AI technologies like RFID and IoT [30]. AI has major impact on the halal status of food products throughout the supply chain by putting policies in place to prevent and guard against integrity compromise. AI can also improve supply chain operations by resolving issues with product cost and quality. This ultimately results in increased supply chain profitability by influencing pricing and coordinating systems [31]. AI may also enhance traceability and support the sustainability, eco-efficiency, quality, and safety of integrated food supply chains. It is feasible to improve control and adaptability by integrating AI into blockchain-based systems used for food supply chain monitoring (Figure 2) [17].

AI can also strengthen the sustainability, eco-efficiency, quality, and safety of integrated food supply chains and enhance traceability. The capacity to regulate and adjust to changes can be improved by integrating AI into blockchain-based applications for food supply chain monitoring.

[32]. Research shows that AI algorithms outperform other approaches, underscoring revolutionary potential of AI to efficiently manage the food supply chain. However, it is crucial to consider the ethical implications and ensure that AI systems do not negatively impact society or the environment [33].

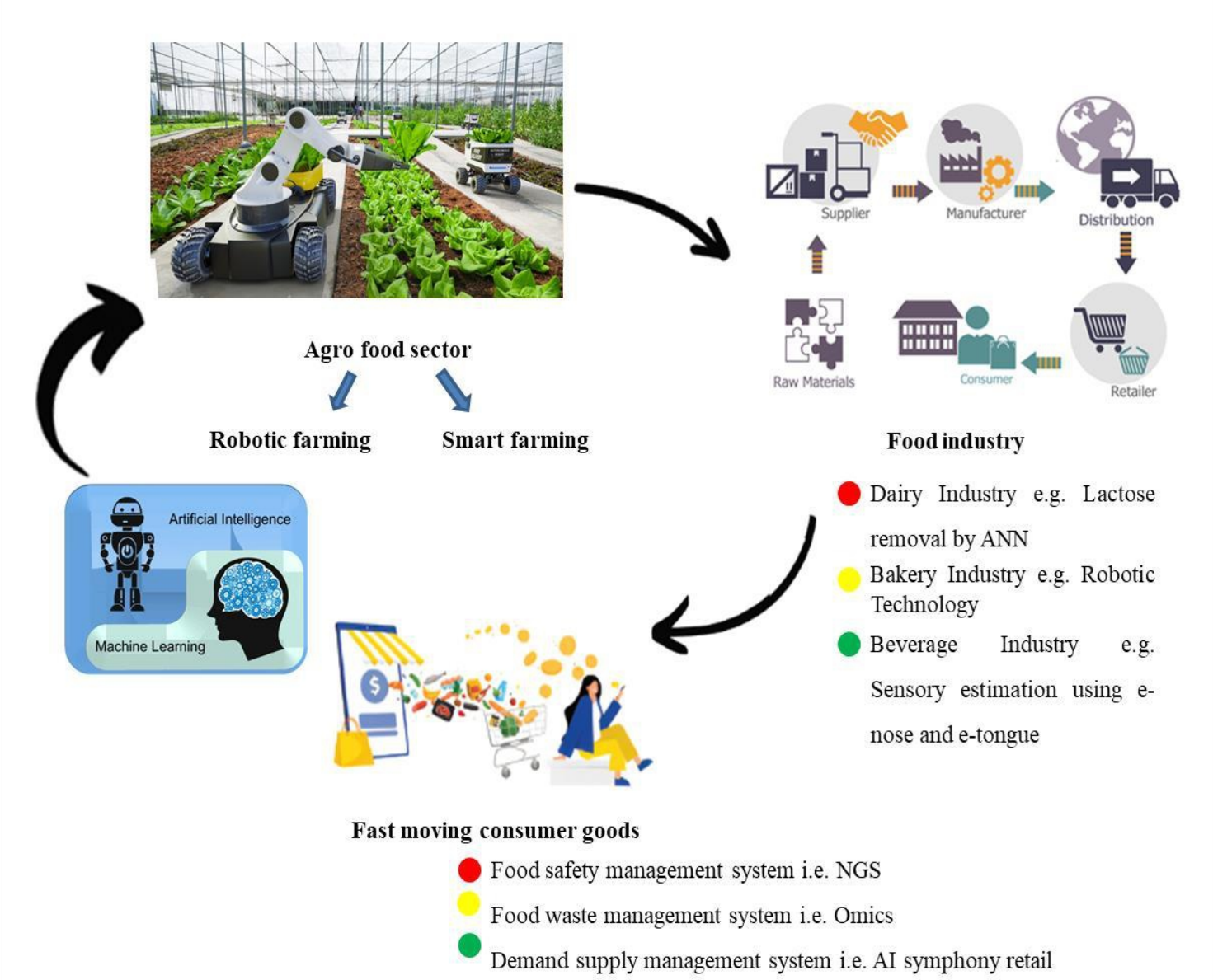

Figure 2. AI mechanism in food processing and food supply chain

6. Food traceability with AI

AI makes quality assurance transparent in food traceability systems. Food safety traceability systems can successfully address the issues associated with traditional traceability systems, such as insufficient reliability and complicated data storage, by AI and IoT big data [34]. This relationship makes it easier to trace the provenance of food products and provides information on how to make data about food safety and quality more reliable and accessible. According to experts, applying technology in the food business can help to evaluate the quality of food products, offering the chance for precise and reliable assessments [35]. Incorporating block chain technology, IoT and AI into food monitoring could improve intelligent decision-making, safeguard privacy, and eventually help to identify the best ways to ensure food quality [36]. The significance of traceability in ensuring food safety and quality has been underlined, particularly with the advent of sophisticated packaging methods that make it possible to track quality data, such as freshness detection, and utilizing traceable and identifiable packaging [37].

Furthermore, it has been acknowledged that a significant step towards digitizing management system has been implemented for consistent conformance testing in healthcare institutions. This advancement enables the efficient application of artificial intelligence in quality control and post-market surveillance [38]. Traceability and transparency are acknowledged as essential components of food safety legislation. They enhance public confidence in the effectiveness of food safety procedures, rectify the information mismatch, and rebuild public trust [39]. Moreover, the market-oriented nature of traceability has important ramifications for the agro-food supply for sustainability of the network. It draws attention to traceability's likely effects on sustainability as well as its market-driven and economic justifications [40]. The ability of the food traceability system to manage emergencies has been connected to its efficacy, underscoring the need to promptly and effectively detect, separate, and resolve issues as well as reducing the effects of food recalls [41].

7. Recognition of food flavour patterns using AI

The ability of machine learning algorithms to identify food flavour patterns which has advanced remarkably. Predicting how flavours will be perceived by the senses, creating novel natural flavour compounds, and enhancing food quality are just a few of the uses for these algorithms. Additionally, by using targeted metabolomics and machine learning models, it has been found that statistical and machine learning methods may be combined to understand flavour chemistry and accurately anticipate how fruit flavours would be perceived by the senses [42]. Through transfer learning procedures, similar innovative uses of machine learning algorithms have created new natural flavour compounds with desired properties. The food business is using machine learning more and more for information identification through machine vision systems, in addition to detecting flavour patterns. These technologies are becoming more and more common for identifying food defects and analysing their ripeness [43]. Highlighting the importance of machine learning for sustainable advancements in the food business, combining machine learning and big data analytics has enhanced decision support in agriculture, yield prediction, disease identification, and species sorting in the agri-food sector (Fig 3) [44]. The industry has made extensive use of AI due to its several advantages over the traditional method. Even if all algorithms are known to be accurate and reliable, selecting one over the other requires carefully weighing the advantages and disadvantages of each. Each algorithm has pros and cons of its own, thus choosing one for a particular application in the food sector needs to be done case by case.

8. The potential of AI in the food sector

The analysis of the literature on the food business makes it clear that a significant amount of investment is needed in the food processing and manufacturing industry. AI-powered systems can more easily identify a range of issues in food production than man-based methods. It has also been noted that researchers are actively working in this area. The artificial intelligence technology detects possible intimidation and then warns farmers so they may prepare accordingly. Furthermore, in order to maximize the use of the resources available to farmers, the artificial intelligence method will recommend convincing activities. Machine learning and deep learning methods may also be applied to satellite data to analyze surface of the Earth.

Finding locations where the government or its owners may offer facilities to improve the crop and raise the output is the main objective. It has also been observed that farming is antiquated and stagnant in many regions of the world. It could soon be replaced by smart farming. In the near future, artificial intelligence might be used for smart farming and help with the existing state of affairs. Yields might rise by at least 60% with a good smart farming setup. There will be a multitude of solutions to eliminate waste in the food manufacturing business, even though machine learning and artificial intelligence are promising techniques.

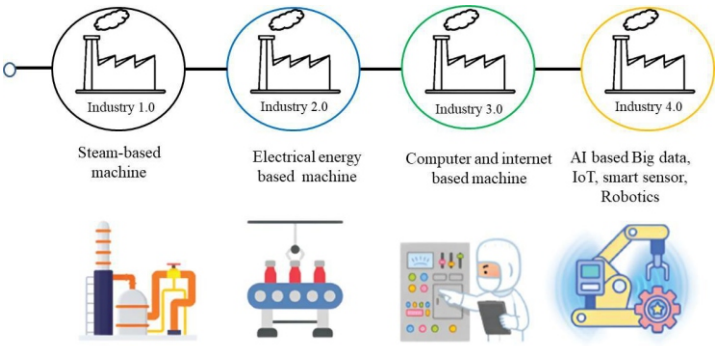

Fig. 3. Industrial revolution [45]

9. Global Food Security and AI

Artificial intelligence offers enormous potential for successfully addressing the various challenges associated with agriculture and food supply networks. AI methods are essential for knowledge modelling, service development, and decision-making in agri-food applications. The entire food supply and value chain can benefit from the vertical use of AI, which offers a variety of features to boost productivity and efficiency [46]. It has been shown that AI robots, machine learning, and deep learning have the ability to precisely predict agricultural output, detect crop diseases, and improve crop quality. These developments greatly increase global food security and eventually lead to increased farm profitability [47]. In view of growing concerns about food security and climate change, Lakshmi and Corbett [48] emphasize the critical role AI plays in enhancing agricultural productivity and sustainability. According to Malhotra and Khan[49], AI in agriculture is vital to achieving global food security. They draw attention to how AI could improve sustainable farming practices, precision agriculture, and crop data management. Water conservation and labour reduction are two advantages of agricultural mechanization. It also allows farmers to diversify their crops, which raises their per capita income. In the past, irrigation systems have involved a lot of manual labour and are weather-dependent [50]. Crop harvesting is impacted by drought. Although irrigation technologies were developed to increase agricultural output, they have resulted in excessive water usage, which may have detrimental effects on our future [51]. This is the beginning of precision irrigation, a ground-breaking technique that has had a significant impact on the world stage. Additionally, according to Martos et al. [52], AI has the potential to completely transform the agricultural industry, particularly in the areas of intelligent farming and Agriculture 5.0. Improving supply chain operations and traceability would be the primary means of bringing about this transition. It has also been recognized that artificial intelligence can address plant disease and pest problems, which pose a threat to food security and cause large financial losses. Using cutting-edge deep learning techniques, artificial intelligence is essential for the

prompt identification and classification of plant diseases, advancing Industry 4.0 and expanding agricultural opportunities [53].

10. Constraints and Limitations

Despite all of these advantages, there are a number of drawbacks to AI technology that make things harder. First and foremost, unemployment is the largest social problem and might be dangerous. In practice, human intervention will decline as smart machines and robots replace the majority of repetitive tasks and activities; this will have a big effect on employment standards. Another problem with technology is that machines can only do tasks for which they have been built or programmed; otherwise, they usually malfunction or produce unrelated outputs. Furthermore, considering that AI is always changing and that hardware and software must be updated to suit new needs, the high development and maintenance expenses of smart machines and clever computers may be seen as technological constraints of AI technologies. Machine repair and maintenance are expensive. They are quite complex gadgets, and the cost of the creation is very high. Another issue is the expensive cost of these applications, which might result in higher item prices. Beyond the possibilities offered by smart and computerized technology, there may also be risks and sustainability issues, such as high energy consumption, the problem of e-waste, market concentration, job displacement, and even the ethical framework.

11. Conclusion and Future Prospects

In conclusion, artificial intelligence has been a significant factor in the food business for a number of reasons, including modeling, prediction, control tools, food drying, sensory assessment, quality control, and resolving challenging issues in food processing. In conclusion, AI has been playing a major role in the food industry for various intents such as for modeling, prediction, control tool, food drying, sensory evaluation, quality control and solving complex problems in food processing. Apart from that, AI may improve company tactics since it can forecast sales and enable yield increases. AI is well known in the food business for its ease of use, precision, and cost-effectiveness. A comprehensive summary is provided on the uses of AI, its benefits and drawbacks, and how algorithms are integrated with various sensors like E-nose and E-tongue in the food sector. Additionally, a guideline has been put forth as a methodical process for creating the right algorithm before applying the AI model in the field related to the food industry. This will help motivate researchers and industry participants to explore the current technology that has been shown to yield superior results.

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